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Feasibility Study for Downsizing EF7 Engine, Numerical and Experimental Approach

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ABSTRACT

Engine downsizing has been considered as a promising approach for reducing CO_2 emitted from internal combustion engines since the long-term goal of the International Energy Agency was published in 2011. By engine downsizing, the engine dimensions would decline while the performance is preserved. So, the fuel consumption and engine emission decrease as well as power to weight ratio increases. In this study, the Iranian national engine EF7 is considered as the target of downsizing and three conceptual designs for downsizing are propose: 3-cylinder gasoline turbocharged (EF7α), 3-cylinder CNG turbocharged (EF7β), and 3-cylinder CNG turbocharged with improved compression ratio (EF7γ). The performance of each concept is investigated and compared with the base engine employing a hybrid-structured engine simulation tool involving a 1D model for engine components and a thermodynamic two-zone model for the combustion process. The model is validated with experimental data for the base engine. Indeed, the performance of the gasoline-fueled version of downsized engine EF7α is estimated close to the base engine. Shifting the fuel to CNG (EF7β) would lead to lower and poor performance of the engine, especially in low load regions. Modification of spark timing would somehow solve the problem however deficiency in lower engine speeds remains. Employing the anti-knock index as the main advantage of CNG as a fuel for the spark-ignition engine, the third concept (EF7γ) is introduced by improving the compression ratio. Results show that a 3-cylinder CNG fueled turbocharged engine with an improved compression ratio would be a good choice for EF7 downsizing.

1) Introduction

The idea of engine downsizing, reducing the displacement volume besides keeping the performance fixed, as an effective solution on the performance enhancement [1], emission reduction [2], and frictional loss decrease [3] is tended by the researcher as well as the long term goal of International Energy Agency (IEA) was published in 2011 [4].

Although extended works such as employing additives [5] and Low-Temperature Combustion [6] were carried out, downsizing is still considered as the most promising approach to achieve IEA 2030 goal, 50% reduction in mean released emission, which brings 32% emission reduction at European markets between 2006 and 2015 [7].

In general, downsized engines are designed based on the bore, connecting rod length, and or the number of cylinders reduction. It is obvious that to obtain the performance, utilizing the boost technologies such as supercharger, turbocharger, Direct Injection (DI), and Variable Valve Timing (VVT) is essential. However, running these technologies may have some challenges namely: knock, super-knock, pre-ignition, and also electrification [8-10].

The range of employed techniques for engine downsizing can be considered from redesigning of engine components to general new engine designing or even the Engine Management System (EMS). Although in recent years, the research focus is shifted to coping with the operational challenges and performance improvement rather than redesigning [11 and 12], it seems there is still a great potential for ultra-downsizing [13]. The employed techniques on engine downsizing have been illustrated in the following;

A 50% downsized 3-cylinder engine optimal designing has been reported by Hancock et al. [14] focusing on design structure and employed technologies and 30% fuel economy and also CO_2 reduction are reported as their optimal design. The concept of using pneumatic hybridization instead of electric ones for ultra-downsizing was reported more cost-efficient by Dönitz et al. [15]. The opportunity of a spark-ignition engine 40% downsizing employing high octane bio-fuels and cooled EGR was investigated by Splitter and Szybist [16].

Furthermore, charge cooling with a tracer-based two-line Planar Laser-Induced Fluorescence (PLIF) technique in an optical Gasoline Direct Injection (GDI) engine was introduced as an idea to increase volumetric efficiency and Compression Ratio (CR) for downsized engine by Anbari et al. [17].

Also, Turner et al. [18] have achieved 35% CO_2 reduction by designing a 60% downsized engine from a 5L, 8-cylinder V-type Jaguar Land Rover engine.

More efficient turbulent flow at intake port in part-load operation was achieved using a new design of intake system by Millo et al. [19] while it was not realized at full load.

Cooperating of this new design via advancing of Inlet Valve Closing (IVC) and employing turbocharger was introduced as an effective way to improve SI engines performance. In 2015, Severi et al. [20] asserted that 20% displacement volume reduction besides providing right-size engine maximum power of studied GDI engine is achievable via 11% piston bore reduction and using both engines boosting and spark advancing, in a numerical investigation.

The concept of designing a boosted uni-flow scavenged direct injection gasoline engine to achieve more than 50% downsizing is presented by Ma and Zhao [21] for a two-stroke engine. Furthermore, friction loss investigation due to employing micro-geometry piston bearing [22] and oil pan design for modern downsized engine [23] was studied in 2017.

Investigating the literature clearly shows the important role of engine downsizing on emission reduction. On the other hand, considering the trend line of the Iran-domestic industries besides the daily-increasing demand of releasing clean engines may strongly portrait the need for downsized engines in the Iran markets.

In consequence, in this research, the Iranian national engine, EF7, is investigated for the feasibility study of downsizing.

The Naturally Aspirated (NA) 4 cylinder engine is considered as the base engine and 3 downsized versions are introduced using the cylinder reduction strategy (3 cylinder engine) besides utilizing turbocharger technology.

To achieve this aim a thermodynamic one-dimensional model which can investigate the base engine performance as well as applying turbocharger, cylinder reduction, and fuel shifting from gasoline to Compressed Natural Gas (CNG) is employed. Indeed, to evaluate the validity of numeric results, and experimental estimation of engine performance in 3 cylinder conditions, the fuel cut-off strategy is applied to

the one cylinder of 4 cylinder EF7 Turbo-Charged (TC) engine. It is worthy to be noted that, in this strategy, the acceptable estimation of 3 cylinder engine performance is achievable by deleting the frictional losses of the deactivated cylinder.
Furthermore, the model results in fuel cut-offed mode are compared via experimental results for a double validity check. In the next step, the fuel is shifted to the CNG to investigate the performance of the CNG-fueled downsized engine. All in all, it can be asserted that the main novelty of this research is investigating the feasibility of EF7 downsizing for the first time and also the performance improvement study at the low-speed condition in case of fuel shifting to the CNG.

2) Model Description

The investigation of mass and energy equations for each component is mainly used in engine one-dimensional (1D) simulation [24]. The engine performance is finally estimated by the combination of 1D simulation results and thermodynamic simulation of the combustion process.
So, the model has illustrated in two subsections namely; component and combustion simulations. Furthermore, the schematic of the operating model is shown in Figure 1.

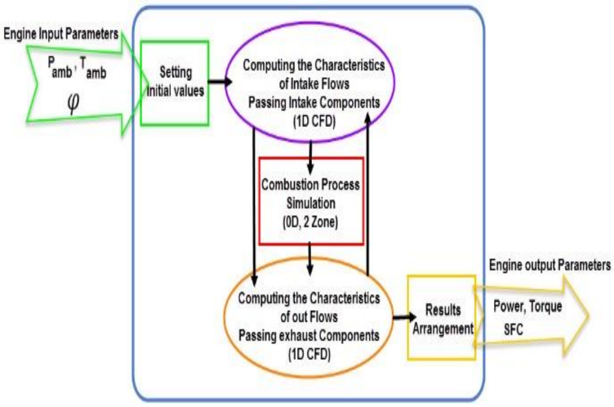

Figure 1: Schematic of the model

1-2) Component Simulation

1D simulation needs to solve mass, energy, and Navier–Stokes equations, simultaneously [25]. The trapped mass of each component is calculated by mass conservation equation, the Energy equation is expanded in transient form using work and convectional heat loss definitions and momentum conservation equation is considered along with each component. Respectively these equations are:

$$\dot{m}_{sub} = \sum \dot{m}_e - \sum \dot{m}_i \tag{1}$$

$$\frac{d(me)}{dt} = P\frac{dV}{dt} + \sum\nolimits_i \dot{m}_i\, h_i - \sum\nolimits_e \dot{m}_e\, h_e - h_g A(T_{gas} - T_{wall}) \tag{2}$$

$$\frac{\dot{m}}{dt} = \frac{dpA + \sum_i \dot{m}_i\, u + \sum_e \dot{m}_e\, u}{dx} - \frac{4C_f \frac{\rho u^2}{2}\frac{dxA}{D} - C_p\left(\frac{1}{2}\rho u^2\right)A}{dx} \tag{3}$$

In these equations, $\dot{m}_i$ and $\dot{m}_e$ are the mass flow rates at the entrance and exit of each component which are defined as

$$\dot{m} = \rho U A \tag{4}$$

where ρ, A, U indicate density, area, and velocity of flow. Indeed, P, V, e, h, h_g, T_{gas} and T_{wall} in the energy equation are pressure, volume, specific internal energy, specific enthalpy, convection heat transfer coefficient, stream temperature, and wall temperature, respectively. Convection heat transfer coefficient is described as,

$$h_g = \frac{1}{2}\,\rho\, C_f\, U_{eff}\, C_p\, Pr^{-\frac{2}{3}} \tag{5}$$

where C_f , U_{eff}, C_p and Pr define friction coefficient, effective velocity, specific heat coefficient, and Prandtl number, respectively. Considering pipes roughness, the friction coefficient is defined by Nikuradse equation [27],

$$C_{f(rough)} = \frac{0.25}{\left[2\log_{10}\left(\frac{1D}{2h}\right) + 1.74\right]^{0.25}} \tag{6}$$

where D is the diameter of the pipe and h is the height of roughness. In the momentum equation, C_p is pressure loss coefficient which is defined as,

$$C_p = (P_{\mathrm{i}} - P_{\mathrm{e}})/\left(\frac{1}{2}\rho U_{\mathrm{i}}{}^2\right) \tag{7}$$

Indexes i and e show inlet and outlet conditions.

2-2) Combustion Simulation

A two-zone thermodynamic model is employed for combustion process simulation. The combustion chamber is divided into the burnt and unburned zones and the first law of thermodynamics, ideal gas equation of state besides engine geometrical correlations are applied on each zone. The schematic of the two-zone model is shown in Figure 2.

It should be noted that the heat transferred between two zones is ignored and it is assumed that a proportion of charge, due to the Wiebe function, enters the burnt zone in each time step.

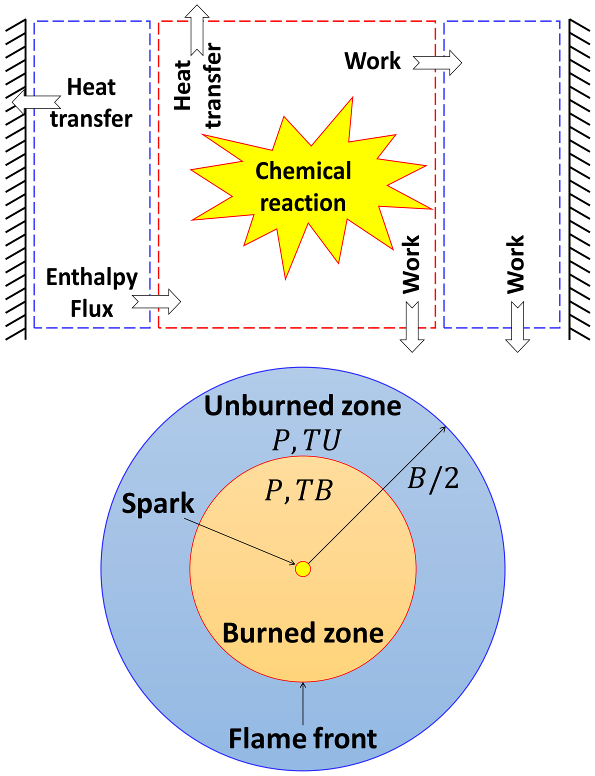

Figure 2: Schematic of applied two-zone model

The heat release rate is also defined by the Wiebe function which is modified for CNG and gasoline blends combustion [28],

$$x_b = 1 - exp\left[-Ea\left(\frac{\theta - \theta_{ig}}{\Delta\theta}\right)^{m+1}\right] \tag{8}$$

Here, x_b, Ea, and θ_{ig} are the mass fraction of burnt fuel, activation energy, and spark time, respectively. Energy equation, assuming charge and combustion products as the ideal gases and considering SI combustion process, can be written as [28],

$$\frac{d(M_B E_B)}{d\theta} + \mathrm{P}\frac{\mathrm{dV_B}}{d\theta} + \mathrm{Q_B} = \eta\ \mathrm{LHV}\ \mathrm{M_f}\frac{dx_b}{d\theta} + h_U\frac{dM_B}{d\theta} \tag{9}$$

$$\frac{d(M_U E_U)}{d\theta} + \mathrm{P}\frac{\mathrm{dV_U}}{d\theta} + \mathrm{Q_U} = h_U\frac{dM_U}{d\theta} \tag{10}$$

where M, E, V, P, η, LHV , and h are the symbols of mass, internal energy, volume, pressure, combustion efficiency, the low heating value of fuel, and specific enthalpy and the indexed U and B refer to the unburnt and burnt zones. The heat transferred from the unburned zone is equal to $x_b Q$ it is considered as $(1 - x_b)Q$ for the burnt zone, where Q is the total heat transfer from the Woschni correlation [29].

$$\frac{\mathrm{dQ}}{d\theta} = h_c A_c \frac{dT}{d\theta} \tag{11}$$

$$h_c = 130\ P^{0.8} U^{0.8} B^{-0.2} T^{-0.55} \tag{12}$$

Here, A_C, T, and U are the effective area of heat transfer, in-cylinder gas temperature, and gas local speed which is calculated by the mean piston velocity. It should be noted that the temperature of these equations are the mean cylinder temperature which is calculated as [28],

$$T = \frac{x_b C_{v_B} T_B + (1 - x_b) C_{v_U} T_U}{x_b C_{v_B} + (1 - x_b) C_{v_U}} \tag{13}$$

C_v is the specific heat coefficient in terms of constant volume and the volume of combustion chamber defined by engine geometrical correlation [28].

$$V = V_c + \frac{\pi B^2}{4}\left(l - a - a\cos\theta - \sqrt{l^2 - a^2\sin^2\theta}\right) \tag{14}$$

Here, $\mathrm{V_c}$, l, and a are the clearance volume, connecting rod length, and crank radios, respectively, and θ refers to the crank angle. The total volume is divided into the two burnt and unburned sections, so the state equation of ideal gas for each zone is like;

$$\frac{PV_B}{RT_B} = M_B = x_b M_t \tag{15}$$

$$\frac{PV_U}{RT_U} = M_U = (1 - x_b) M_t \tag{16}$$

where, M_t refers to the total trapped mass in the cylinder. In addition to the noted correlations, some other considerations are applied to the control volume due to the kind of component, operation, and characteristics. Some of them are listed in the following;

- The velocity, turbulence, pressure loss, and other features of charge flow would be affected by the valve lifting profile.
- The main features of the flow passing the components, such as the charge/discharge coefficients, are adopted from the company data.
- The valve timing is adopted from the engine operating map.
- The losses caused by the injection type would be affected depends on the characteristics of the injector such as static injection, dynamic injection, injection duration, injection timing, injection angle, and the number of nuzzles. In this study, the effect of the number of nuzzles is ignored.
- The turbocharger is modeled by the own operating map which is provided by the producer, so the turbine rotational speed, efficiency, power, and boosted pressure calculated by the amount of flow passing the turbine blades.
- The passing flow of turbine blades is controlled by the wastegate lifting profile which is adopted from the engine operating map.
- Ignition timing, fuel-injected, and equivalence ratio are also adopted from the engine operating map.
- The friction loss of engine components is defined due to the engine frictional test.
- The compressor bypass flow, cyclic variations, angle of throttle, added fuel by canister valve, the losses by the oil pump, water pump, alternator, and other accessories are ignored due to the kind of simulation.

3) Validation

To investigate the EF7 engine performance and also the capability of its downsizing, two 1D models are provided using described equations at the model description section in the GT-Power commercial software environment. The first model simulates the NA engine and the second one is developed to simulate TC engine performance. In addition, both models are able to handle fuel shifting from gasoline to CNG. The main characteristics of EF7 engines are reported in table 2.

Table 2: The main characteristics of engines

Engine	EF7 NA [30]	EF7 TC [31]
Type	4 inline cylinders	
B × S	78.6×85 mm	
L	134.5 mm	
CR	11	9.6
IVC	40° aBDC	26° aBDC
EVO	50° bBDC	25° bBDC

The results of simulations for NA and TC engines fueled with both, gasoline and CNG, at full load condition are compared with the experimental carried out in Irankhodro Powertrain Company (IPCO).

The accuracy of measurement instruments is reported in Table 3, and also the schematic of the test room is shown in Figure 3. It should be noted that the entire engine input parameters are adopted from the engine operating map. Brake torque, power, Brake Mean Effective Pressure (BMEP), Brake Specific Fuel Consumption (BSFC) in the operating engine speeds are considered as the main parameters for validation.

The results for the NA engine show the mean error of brake torque by 5.44% and specific fuel consumption by 2.74% in the case of the gasoline-fueled engine in Figure 4 and Figure 5. The same trend (meanly 10.1% error) is observed for the CNG fueled engine which is shown in Figure 6 for the brake power.

Table 3: The accuracy of measurement instruments

Parameter	Accuracy
In-cylinder Pressure	$\pm$0.1 bar
Engine Speed	$\pm$1 rpm
Crank Angle	$\pm$0.1 CAD
Torque	$\pm$0.1 N.m
Fuel Consumption	0.12%
Equivalence Ratio	$\pm$0.02

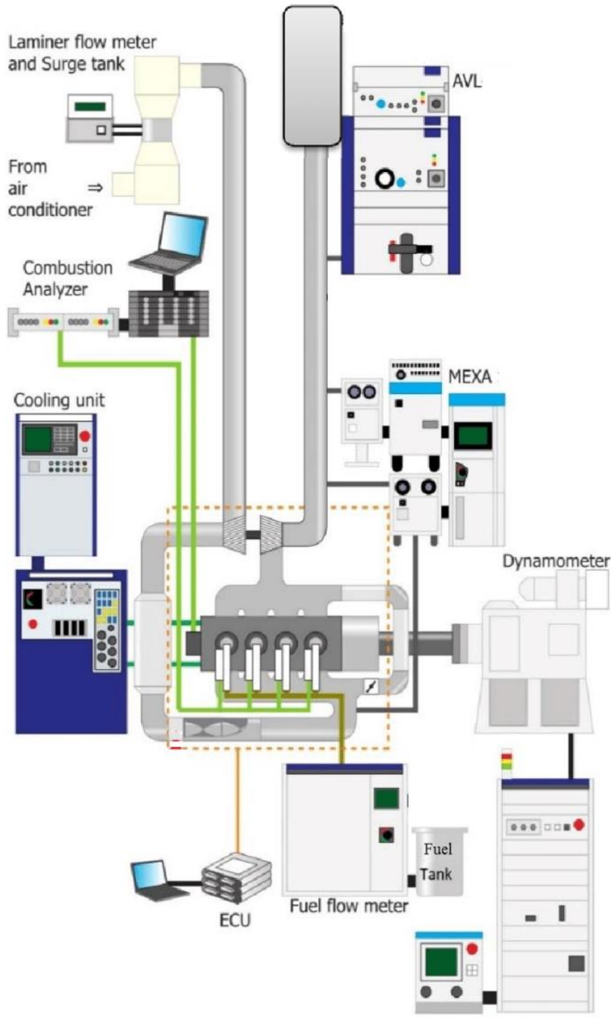

Figure 3: The schematics of the test room

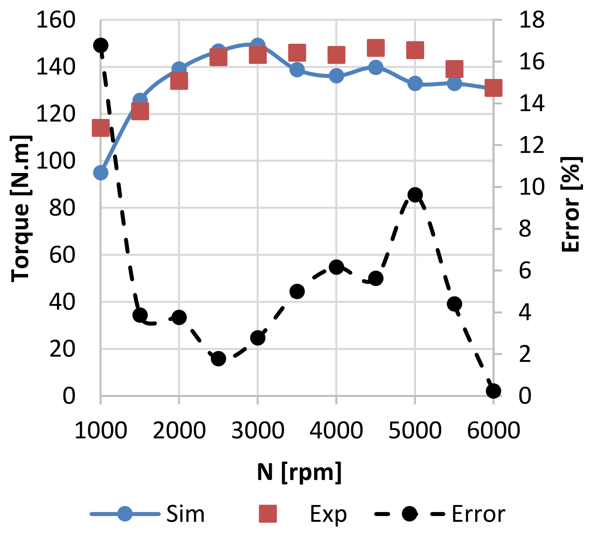

Figure 4: Simulated brake torque via experimental results for gasoline fueled EF7NA

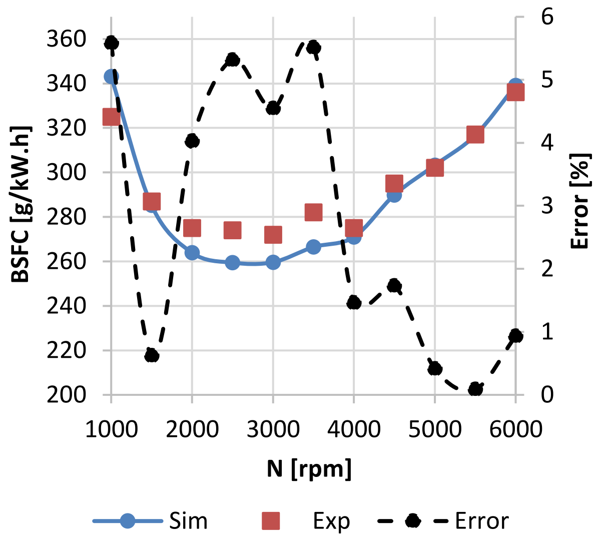

Figure 5: Simulated brake specific fuel consumption via experimental results for gasoline-fueled EF7NA

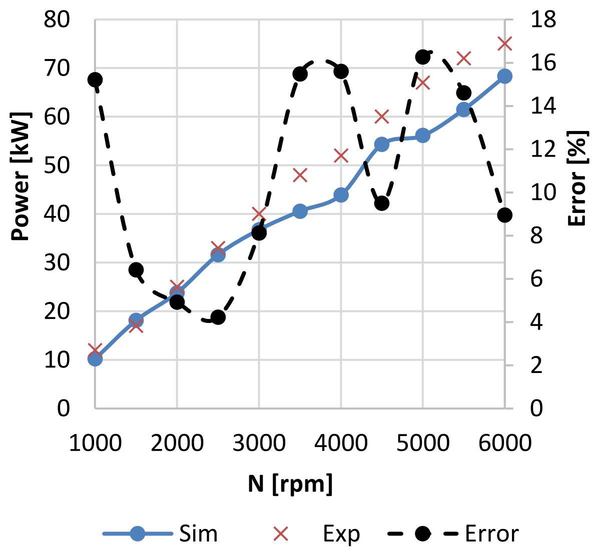

Figure 6: Simulated brake power via experimental results for CNG fueled EF7NA

Simulated brake means effective pressure and specific fuel consumption are also compared via experimental results for gasoline-fueled TC engine in Figure 7 and Figure 8 which show the mean error of 3.73% for BMEP and 7.34% for BSFC. The same trend (meanly 1.1% error) is observed for the CNG fueled engine which is shown in Figure 9 for the brake torque.

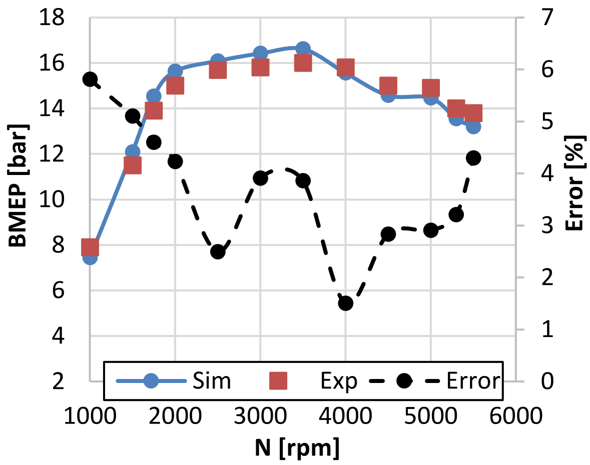

Figure 7: Simulated brake mean effective pressure via experimental results for gasoline-fueled EF7TC

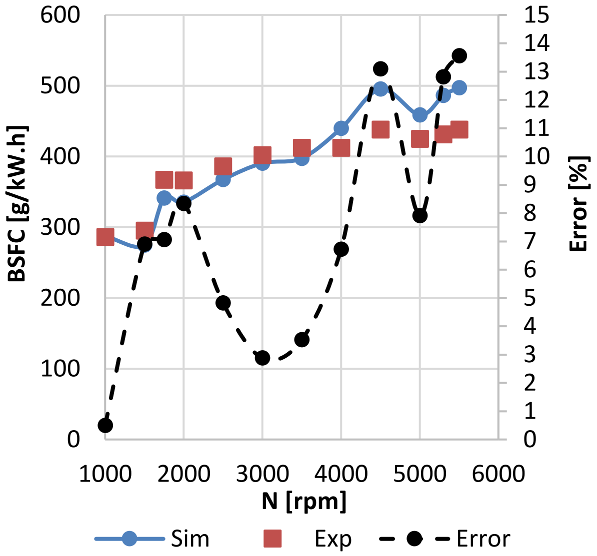

Figure 8: Simulated brake specific fuel consumption via experimental results for gasoline-fueled EF7TC

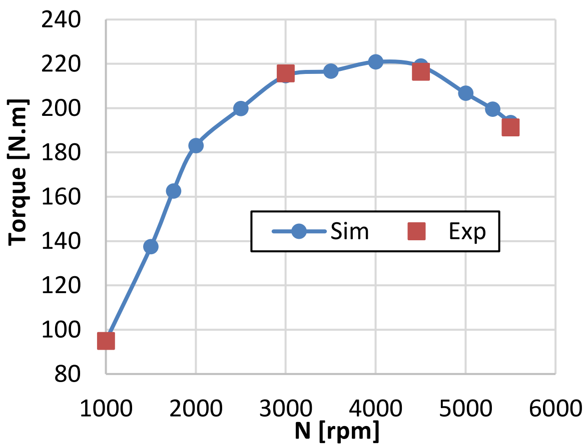

Figure 9: Simulated brake torque via experimental results for CNG fueled EF7TC

Considering Figures 4 to 9, it can be asserted that the provided models are reliable for both gasoline and CNG fueled EF7 NA and TC engine performance evaluation, and also it can be used to study the feasibility of downsizing.

However, to check in more details about the results of the combustion process, the in-cylinder variations for both gasoline and CNG fueled EF7TC engines are compared with experiments shown in Figure 10 and Figure 11. It should be noted that the experimental results shown in these figures are for the 1000 cycles sampling at full load condition of 5500 rpm.

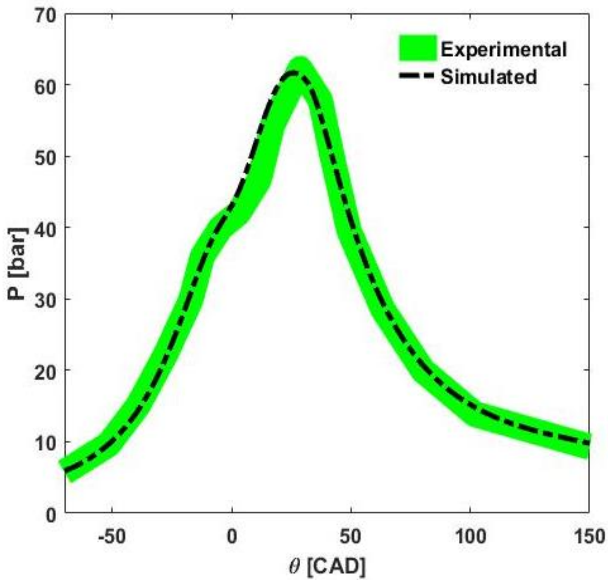

Figure 10: simulated in-cylinder pressure for gasoline-fueled EF7TC

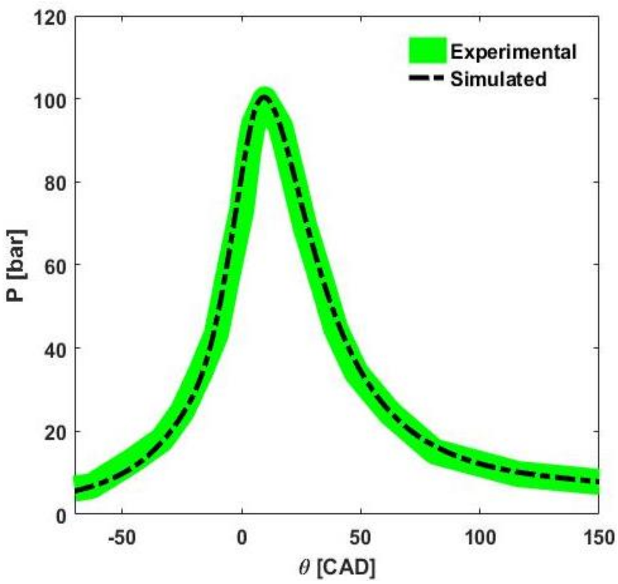

Figure 11: simulated in-cylinder pressure for CNG fueled EF7TC

4) Results and Discussions

Gasoline fueled EF7 NA engine is considered as the base engine for downsizing. The basic characteristics of EF7 NA were reported in Table 2 and the main aim of this study is the introduction of the downsized EF7 employing Iran available technology.

At the first step, considering the gasoline-fueled EF7 TC engine performance, a 3-cylinder gasoline-fueled TC engine is introduced as the first conceptual version of downsized EF7 called EF7α. In the next step, to achieve less emission, the fuel of EF7α is shifted to CNG as the second version which is called EF7β.

Finally considering the poor combustion characteristics of CNG in comparison with gasoline and also its high knock resistance, the third version of downsized EF7, named EF7γ, is introduced by the compression ratio enhancement of EF7β. The main characteristics of the base engine and these conceptual downsized versions are reported in Table 4.

It should be noted that, in this step, the fuel cut-off strategy for a cylinder of gasoline-fueled EF7 TC, is applied at the test setup to have an estimation of the experimental performance of 3-cylinder engine. The results of this strategy are called cylinder deactivated in this study and by removing the losses caused by deactivated cylinder, the results bring an acceptable trend of downsized engine performance.

However, the simulations are carried out for both strategies; cylinder deactivated and real 3-cylinder model.

The concept of EF7α is adopted by gasoline-fueled EF7 TC engine performance which is compared with NA one in Figure 12. As it is shown in figure 12, TC engine produces brake torque almost 1.33 times more than NA one.

In consequence, it can be expected that EF7α has the same performance as the considered base engine. The results of simulations confirm this assertion shown in Figure 13. The results show that the provided power of EF7α is meanly 13.8 more than the base engine. So, it can be asserted that this engine may be the gasoline-fueled version of the EF7 downsized engine.

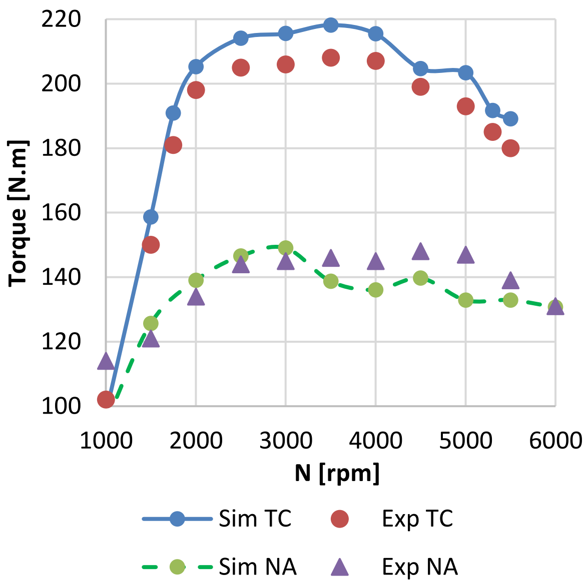

Figure 12: Brake torque comparison, EF7TC via EF7NA

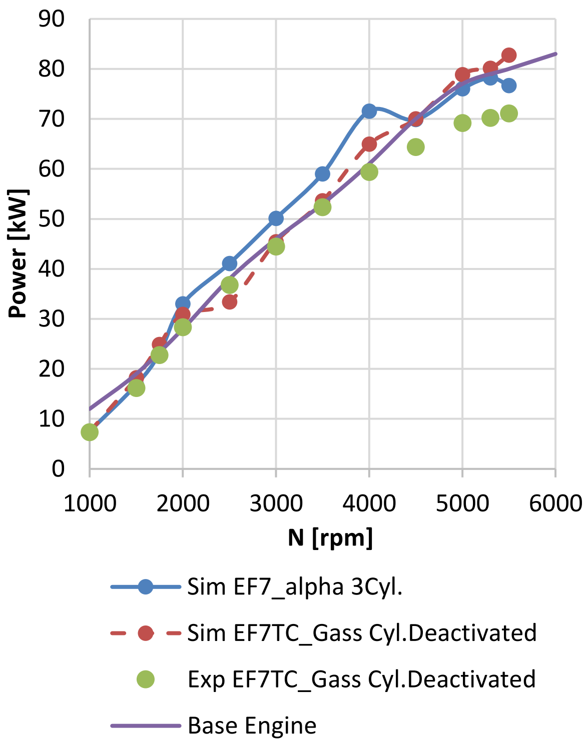

Figure 13: Brake power comparison, EF7α via base engine

To achieve less emission, the idea of employing light hydrocarbon fuels is accepted in different approaches of combustion field, so using CNG as a fuel of downsized engines can be a promising idea having environment friendlier engines. In consequence, the fuel of EF7α is shifted to the CNG and the EF7β is introduced as the second conceptual version of the EF7 downsized engine. The performance of EF7β is shown in Figure 14. The output torque of EF7β is significantly less than both EF7α and the base engine. Less flame speed of CNG in comparison with gasoline causes this poor performance. However, this issue can be handled by spark time advancing. By advancing the spark time, the charge has enough time to combust more efficiently as is obvious in Figure 15. Achieved in-cylinder pressure due to the spark time advancing by 20degrees is such noticeable at the EF7 engine that the EF7β performance with modified spark timing shows the performance like the base engine as it is shown in Figure 16. It should be noted that the performance improvement of downsized engines at low speed is still needed. The same challenge was reported for the CNG-fueled downsized engines in the literature [32 and 33].

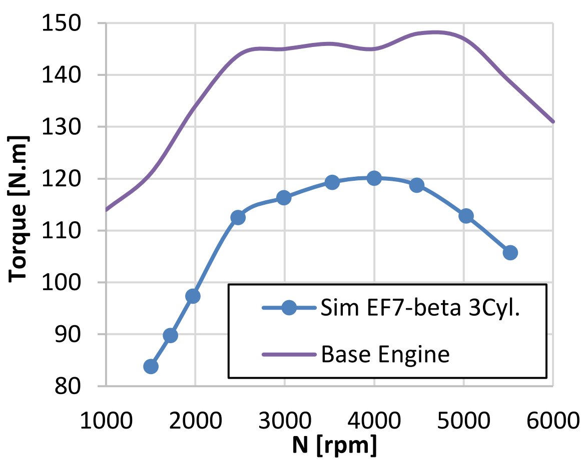

Figure 14: Brake torque comparison, EF7β via base engine

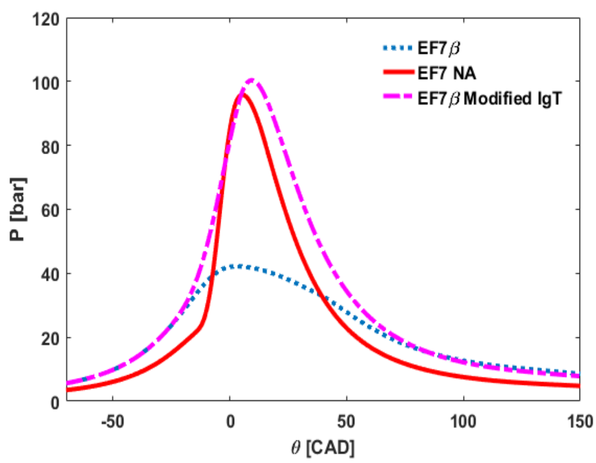

Figure 15: In-cylinder pressure comparison for the base engine, EF7β, and EF7β with modified spark timing

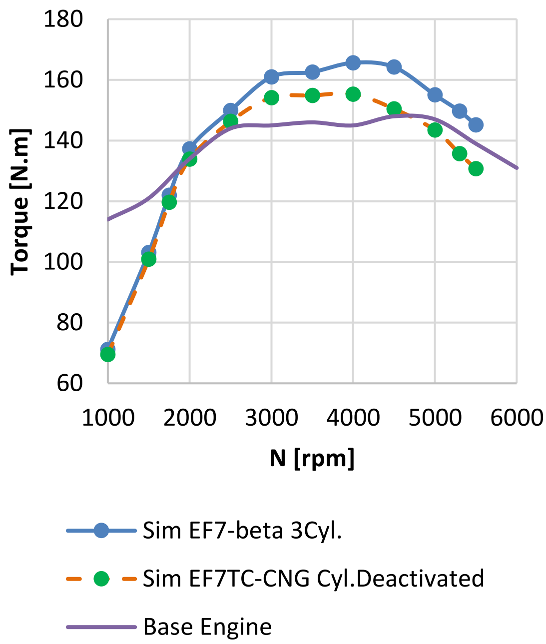

Figure 16: Brake torque comparison, EF7β with modified spark timing via base engine

The challenge of poor performance in CNG fueled downsized engines at low speed has been involved some efforts [32 and 33] and the researchers are continuously trying to find sufficient ways of solving this issue.
One of the most popular combustion characteristics of CNG as the fuel of internal combustion engines is its high anti-knock index which means it can be employed in engines with more compression ratio.
Indeed, the EF7 NA engine had been designed with a high compression ratio, $CR = 11$, before adding a turbocharger. So, it can be re-configured to $CR = 11$ in TC mode with no concern of knock occurrence, and in this way, modified EF7β can be developed to the third version of downsized EF7 called EF7γ.
In addition to higher output torque than the base engine at high speed, EF7γ shows acceptable performance at low-speed operation conditions shown in Figure 15. However, its brake torque is estimated by 8.9% less than the base engine at 1500rpm. The estimated performance of introduced engines is compared in figure 16.
Although the performance of EF7γ is estimated as well as the base engine at all operation conditions, the other concepts namely EF7α and modified EF7β can show the acceptable performance as a downsized engine, too.

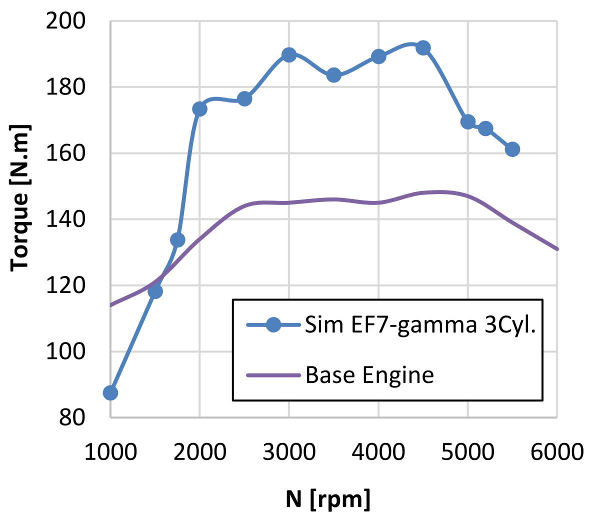

Figure 15: Brake torque comparison, EF7γ via base engine

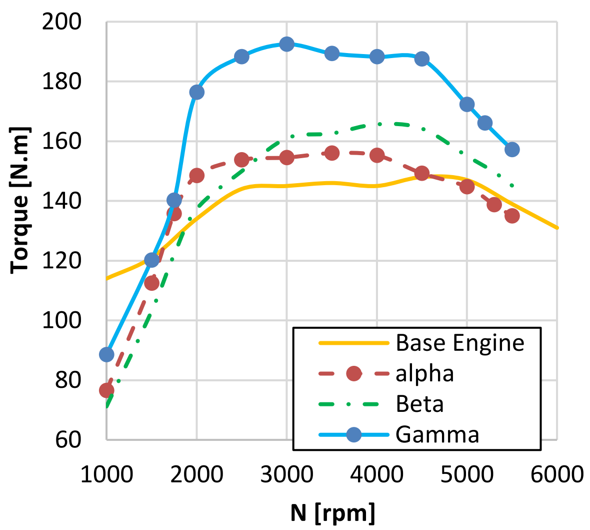

Figure 16: Brake torque comparison, downsized concepts via base engine

5) Conclusions

In this research Iranian national engine, a gasoline-fueled EF7 NA engine was studied to evaluate its downsizing feasibility. Two 1D models were provided to investigate the performance of NA and TC engines with the capability of fuel shifting from gasoline to CNG. After the validation of simulated results, the performance of three versions of downsized engines was compared with the base engine. The main achieved results are listed in the following;

- Provided models are enough accurate to estimate the EF7 NA and TC engine's performance with both gasoline and CNG as the fuels.
- The EF7α version as the gasoline-fueled version of the downsized engine can show the same performance as the base engine.
- The performance of the EF7β version could be in the acceptable range as the CNG fueled version of a downsized engine using modified spark timing.
- The EF7γ version is introduced as the CNG fueled downsized engine with suitable performance even at low-speed operating conditions.

Acknowledgment

The authors have to express their appreciation to Irankhodro Powertrain Co (IPCO) for sharing necessary data during this research.

List of Symbols

A	Area, m^2
B	Bore, m
E	Internal Energy, kj
$\dot{m}$	Mass Flow Rate, kg/s
N	Engine Speed, rpm
P	Pressure, kPa
T	Temperature, K
V	Volume, m^3
V_c	Clearance Volume, m^3
x_b	Burned Mass Fraction

Greek Symbols:

θ	Crank Angle, deg
ρ	Density, kg/ m^3
$\emptyset$	Equivalence Ratio

References

[1] Ravi P, Devanandh V, Pandey SK, Senthilnathan K, Sadagopan K, Patel BP. Quasi-Dimensional Thermodynamic Simulation Study of Downsizing on a Four-Cylinder Turbocharged Engine. advances in Energy Research, Vol. 2 2020 (pp. 563-575). Springer, Singapore.

[2] Cho J, Kim K, Baek S, Myung CL, Park S. Abatement potential analysis on CO2 and size-resolved particle emissions from a downsized LPG direct injection engine for passenger car. Atmospheric Pollution Research. 2019 Nov 1;10(6):1711-22.

[3] Knauder C, Allmaier H, Sander DE, Sams T. Investigations of the friction losses of different engine concepts. Part 2: Sub-assembly resolved friction loss comparison of three engines. Lubricants. 2019 Dec;7(12):105.
[4] International Energy Agency. Policy pathways: improving the fuel economy of road vehicles – A policy package; 2011.
[5] Namar MM, Jahanian O. Energy and exergy analysis of a hydrogen-fueled HCCI engine. Journal of Thermal Analysis and Calorimetry. 2019 Jul 15;137(1):205-15.
[6] Namar MM, Jahanian O. A simple algebraic model for predicting HCCI auto-ignition timing according to control oriented models requirements. Energy Conversion and Management. 2017 Dec 15; 154:38-45.
[7] Hu K, Chen Y. Technological growth of fuel efficiency in european automobile market 1975–2015. Energy Policy. 2016 Nov 1; 98:142-8.
[8] Merker GP, Schwarz C, Teichmann R, editors. Combustion engines development: mixture formation, combustion, emissions and simulation. Springer Science & Business Media; 2011 Sep 24.
[9] Kuhlbach K, Mehring J, Borrmann D, Friedfeld R. Zylinderkopf mit integriertem Abgaskrümmer für Downsizing-Konzepte. MTZ-Motortechnische Zeitschrift. 2009 Apr 1;70(4):286-93.
[10] Smith A. Stroke of genius for gasoline downsizing. Ricardo Q Rev. 2008: Q3.
[11] Budack R, Wurms R, Mendl G, Heiduk T. Der neue 2, 0-l-R4-TFSI-Motor von Audi. MTZ-Motortechnische Zeitschrift. 2016 May 1;77(5):16-25.
[12] Wang Y, Wei H, Zhou L, Li Y, Liang J. Effect of Injection Strategy on the Combustion and Knock in a Downsized Gasoline Engine with Large Eddy Simulation. SAE Technical Paper; 2020 Apr 14.
[13] Morikawa K, Shen F, Yamada T, Moriyoshi Y, Kuboyama T. The Extension of Load Range and Low Fuel Consumption Range Based on the Ultra-highly Boosted Downsized Engine Concept. Transactions of Society of Automotive Engineers of Japan. 2020 Sep;51(5).
[14] Hancock D, Fraser N, Jeremy M, Sykes R, Blaxill H. A new 3-cylinder 1.2 l advanced downsizing technology demonstrator engine. SAE Technical Paper; 2008 Apr 14.
[15] Dönitz C, Vasile I, Onder C, Guzzella L. Realizing a concept for high efficiency and excellent driveability: the downsized and supercharged hybrid pneumatic engine. SAE Technical Paper; 2009 Apr 20.
[16] Splitter DA, Szybist JP. Experimental investigation of spark-ignited combustion with high-octane biofuels and EGR. 1. Engine load range and downsize down speed opportunity. Energy & Fuels. 2014 Feb 20;28(2):1418-31.
[17] Attar MA, Herfatmanesh MR, Zhao H, Cairns A. Experimental investigation of direct injection charge cooling in optical GDI engine using tracer-based PLIF technique. Experimental thermal and fluid science. 2014 Nov 1; 59:96-108.
[18] Turner JW, Popplewell A, Patel R, Johnson TR, Darnton NJ, Richardson S, Bredda SW, Tudor RJ, Bithell CI, Jackson R, Remmert SM. Ultra boost for economy: extending the limits of extreme engine downsizing. SAE International Journal of Engines. 2014 May 1;7(1):387-417.
[19] Millo F, Luisi S, Borean F, Stroppiana A. Numerical and experimental investigation on combustion characteristics of a spark ignition engine with an early intake valve closing load control. Fuel. 2014 Apr 1; 121:298-310.
[20] Severi E, d'Adamo A, Berni F, Breda S, Lugli M, Mattarelli E. Numerical investigation on the effects of bore reduction in a high performance turbocharged GDI engine. 3D investigation of knock tendency. Energy Procedia. 2015 Dec 1; 81:846-55.
[21] Ma J, Zhao H. The modeling and design of a boosted uniflow scavenged direct injection gasoline (BUSDIG) engine. SAE Technical Paper; 2015 Sep 1.
[22] Wróblewski E, Finke S, Babiak M. Investigation of friction loss in internal combustion engine of experimental microgeometry piston bearing surface. Journal of KONES. 2017 Jun 1;24(2):307-13.
[23] Liu J, Liu Y, Bolton JS. The application of acoustic radiation modes to engine oil pan design. SAE Technical Paper; 2017 Jun 5.
[24] Gamma Inc. Users Maunual, volume 61. Gamma Technologies, 2004.
[25] White, F.M., Fluid mechanics, WCB. Ed McGraw-Hill Boston; 1999.
[26] Sonntag RE, Borgnakke C, Van Wylen GJ, Van Wyk S. Fundamentals of thermodynamics. New York: Wiley; 1998.

[27] Nikuradse J. Laws of flow in rough pipes. Washington: National Advisory Committee for Aeronautics; 1950 Nov 1.

[28] Heywood JB. Combustion engine fundamentals. 1ª Edição. Estados Unidos. 1988.

[29] Woschni G. A universally applicable equation for the instantaneous heat transfer coefficient in the internal combustion engine. SAE Technical paper; 1967 Feb 1.

[30] Asgari O, Hannani SK, Ebrahimi R. Improvement and experimental validation of a multi-zone model for combustion and NO emissions in CNG fueled spark ignition engine. Journal of mechanical science and technology. 2012 Apr 1;26(4):1205-12.

[31] Gharloghy J, Kakaee A, Forooghifar A. Comparison of EF7 TC engine performance in two modes of CNG and petrol using piston and combustion chamber thermal simulation. Fuel and combustion, 2011, 3(2), pp.1-16.

[32] Streng, S., Wieske, P., Warth, M. and Hall, J., 2016. Monovalent Natural Gas Combustion and Downsizing for Lowest CO2 Emissions. MTZ worldwide, 77(7-8), pp.16-23.

[33] National Research Council, 2015. Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles. National Academies Press.

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امکان‌سنجی عددی و تجربی کوچک‌سازی ابعادی موتور EF7

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چکیده

کوچک‌سازی موتورهای احتراق داخلی پس از انتشار اهداف بلند مدت آژانس بین‌المللی انرژی در سال ۲۰۱۱، به عنوان رویکردی نویدبخش به منظور کاهش انتشار آلایندگی کربن دی‌اکسید مورد توجه قرار گرفته است. در این رویکرد با حفظ مشخصات عملکردی موتور، به کاهش ابعاد آن پرداخته می‌شود. بنابراین، مصرف سوخت و انتشار آلایندگی موتور در پی افزایش نسبت توان به وزن آن کاهش می‌یابند. در این پژوهش، موتور ملی EF7 به عنوان موتور هدف برای کوچک‌سازی در نظر گرفته شده و سه نسخهٔ کوچک‌سازی شده از آن به صورت مفهومی ارائه شده است. این موتورها به ترتیب «EF7α»، «EF7β» و «EF7γ» نام گرفته که با سوخت‌های بنزین و گاز طبیعی کار می‌کنند. پس از اعتبارسنجی نتایج شبیه‌سازی با داده‌های تجربی، عملکرد هر یک از این طرح‌ها بررسی و ارزیابی شد. به عنوان گام ابتدایی در این پژوهش، نتایج بدست آمده بیانگر تطبیق مناسب نتایج شبیه‌سازی با داده‌های تجربی بود. در ادامه عملکرد موتور EF7α به عنوان نسخهٔ بنزین‌سوز موتور کوچک‌سازی شده EF7، بسیار نزدیک به موتور پایه تخمین زده شد. همچنین عملکرد ضعیف ناشی از تغییر سوخت به گاز طبیعی در نسخه EF7β با تعیین زمانبندی مناسب جرقه تا حد قابل قبولی پوشش داده شده هرچند مشکلات افت توان در دورهای کُند همچنان برقرار است. توان موتور در نسخهٔ EF7γ با افزایش نسبت تراکم ارتقا یافت و از مشکلات EF7β تا حد بسیار زیادی کاسته شد.

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